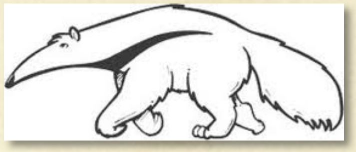
Neutralino Scattering in the pMSSM: Direct Detection & IceCube/DeepCore

Randy Cotta - UC Irvine



In collaboration with:

Matthew Cahill-Rowley, Alex Drlica-Wagner, Ahmed Ismail, Matthew Wood
Stefan Funk, JoAnne Hewett, Tom Rizzo

Snowmass Cosmic Frontier Workshop @ SLAC, March 2013

Questions…

- Which experiment will make the first discovery of $\tilde{\chi}_1^0$?
- What will we learn about $\tilde{\chi}_1^0$ when we see something?
- How have expectations changed since the start of LHC running?

Broader pMSSM Complementarity: Ahmed Ismail, next!

Answers…

- The p(henomenological)MSSM allows robust study of the possibilities using diverse sample of realistic SUSY models. Full details for each model: predictions for any experiment without theoretical over-simplification.
- Experimental analyses are as realistic as possible (and we welcome the opportunity to do better!)

The p(henomenological)MSSM:

- Take the ~120 free parameters in the MSSM, subtract those which are highly constrained by experiment (mostly: new flavor pars.), end up with a 19-dimensional subspace: the pMSSM. Considerably more general than mSUGRA/CMSSM

- Scan the space and subject all points to a rigorous battery of constraints. We are the ONLY collaboration that employs realistic collider bounds in a >7-8 dimensional SUSY space.

- We have ~225,000 pMSSM models with $\tilde{\chi}_1^0$ DM. Sparticle masses are scanned up to 4 TeV giving $\tilde{\chi}_1^0$ masses up to ~2TeV. WMAP relic density is taken as an upper bound on the $\tilde{\chi}_1^0$ relic density.

- This is the 2nd generation of pMSSM models: we can observe the impact of the last ~ 4 years of experiments.

See also pMSSM talks by:

Matthew Cahill-Rowley, Alex Drlica-Wagner, Ahmed Ismail and Tom Rizzo

Why are we comparing
direct detection experiments
with a km^3 neutrino telescope?

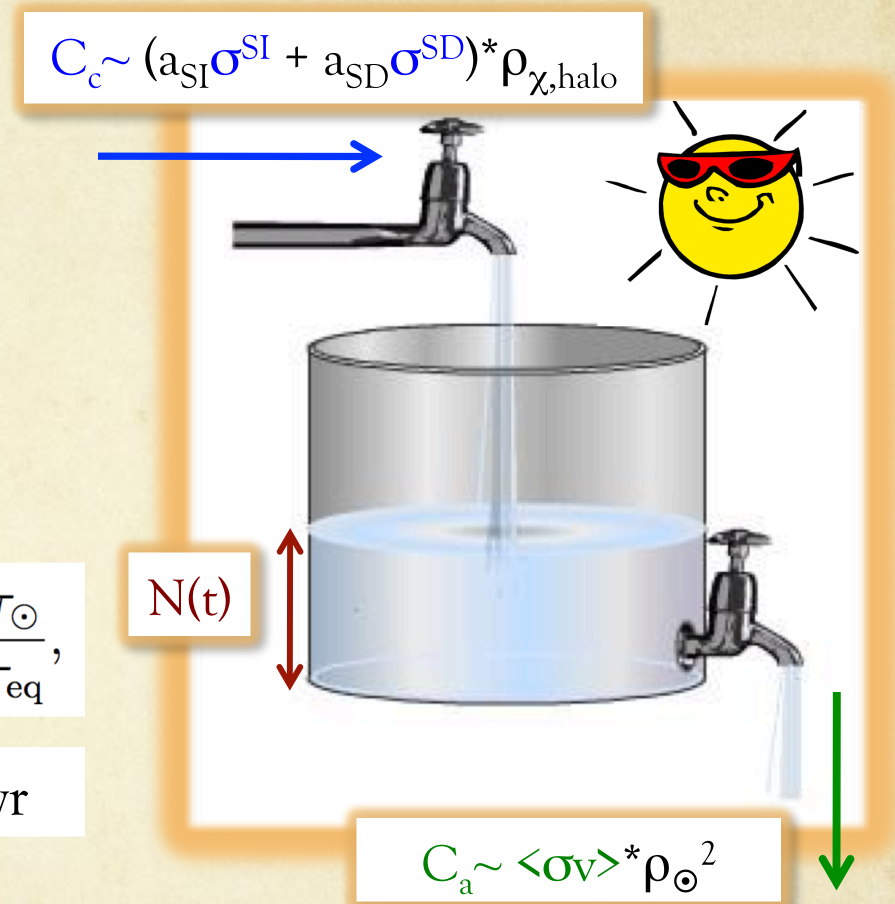
The Solar Dark Matter Search...

WIMPs in Milky Way DM halo scatter off of nuclei in the sun, become trapped in bound orbits and sink to the solar core. This population of WIMPs is also depleted by annihilation:

Solar WIMPs: $$\frac{dN}{dt} = C_c - C_a N(t)^2,$$

Solution: $$\Gamma_a \equiv \frac{1}{2} C_a N^2(\tau_\odot) = \frac{C_c}{2} \tanh^2 \frac{\tau_\odot}{\tau_{eq}},$$

with: $$\tau_{eq} = (C_a C_c)^{-1/2},\ \tau_\odot \sim 4 * 10^9 \text{ yr}$$



In Equilibrium: $\Gamma_a \sim C_c/2 \sim \sigma_{elastic}$

Depends only on elastic cross-section, not $\langle\sigma v\rangle$.

* Press, Spergel (1985); Silk, Olive, Srednicki (1986)

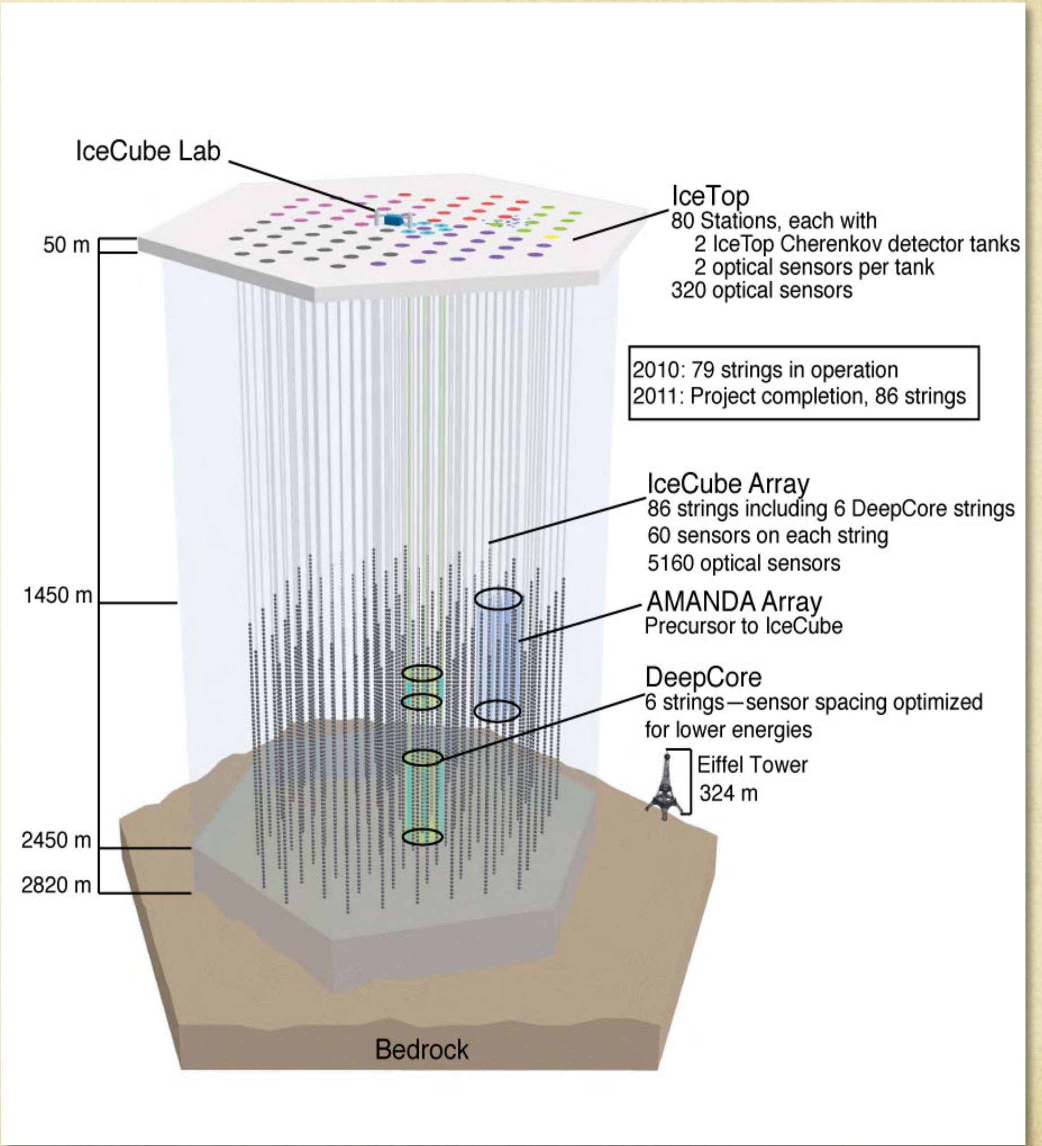
The IceCube-DeepCore (IC/DC) Solar DM Search...

Annihilations of these solar WIMPs inject >1 GeV ν's that propagate out of the sun to neutrino detectors on earth.

IC/DC observes >10 GeV ν's with spatial resolution necessary to discover $\tilde{\chi}_1^0$ with an excess of $\lesssim$100 events/yr correlated with the sun.

The search we discuss here requires ~5 years of useable data, taken over ~10 years.

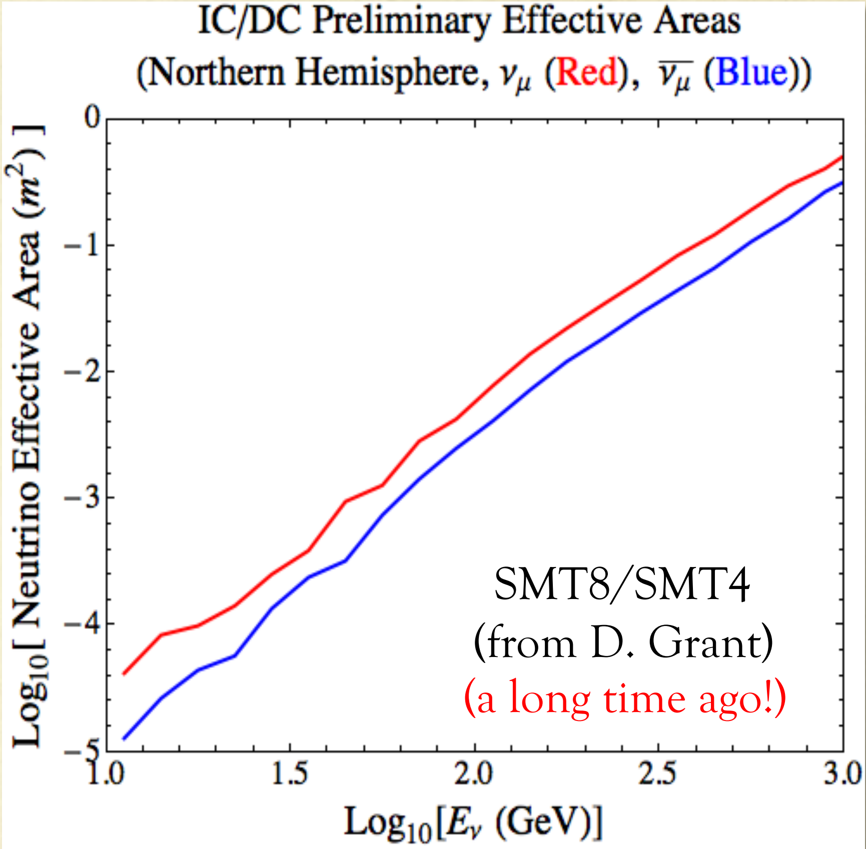
See F. Halzen & D. Grant Talks



IC/DC description: see e.g., 0907.2263

IC/DC event rates from pMSSM Neutralinos…

- Raw ν spectra calculated for each pMSSM model using DarkSUSY 5.0.6.
- Raw spectra are convolved with preliminary detector effective areas:
- Accurate estimates for discovery/exclusion significance are difficult. Detected rates $\Phi^D_\nu \sim \{10\text{-}100\}$ events/yr are plausible.



We take Φ^D_ν>40 events/yr as a criterion for exclusion

Terrestrial Scattering Experiments…

Spin-Independent:

All SI-DD bounds are loosened by a factor of 4 when applied to pMSSM (b/c of uncertainties, e.g., strange content of the proton)

New pMSSM models generated with Xenon100 2011 constraint (1104.2549) applied.

Most plots shown with Xenon100 2012 (1207.5988) applied as well.

Far future: compare to Xenon1T (1206.6288) and LUX+Zeplin (R. Gaitskill slides) forecasts.

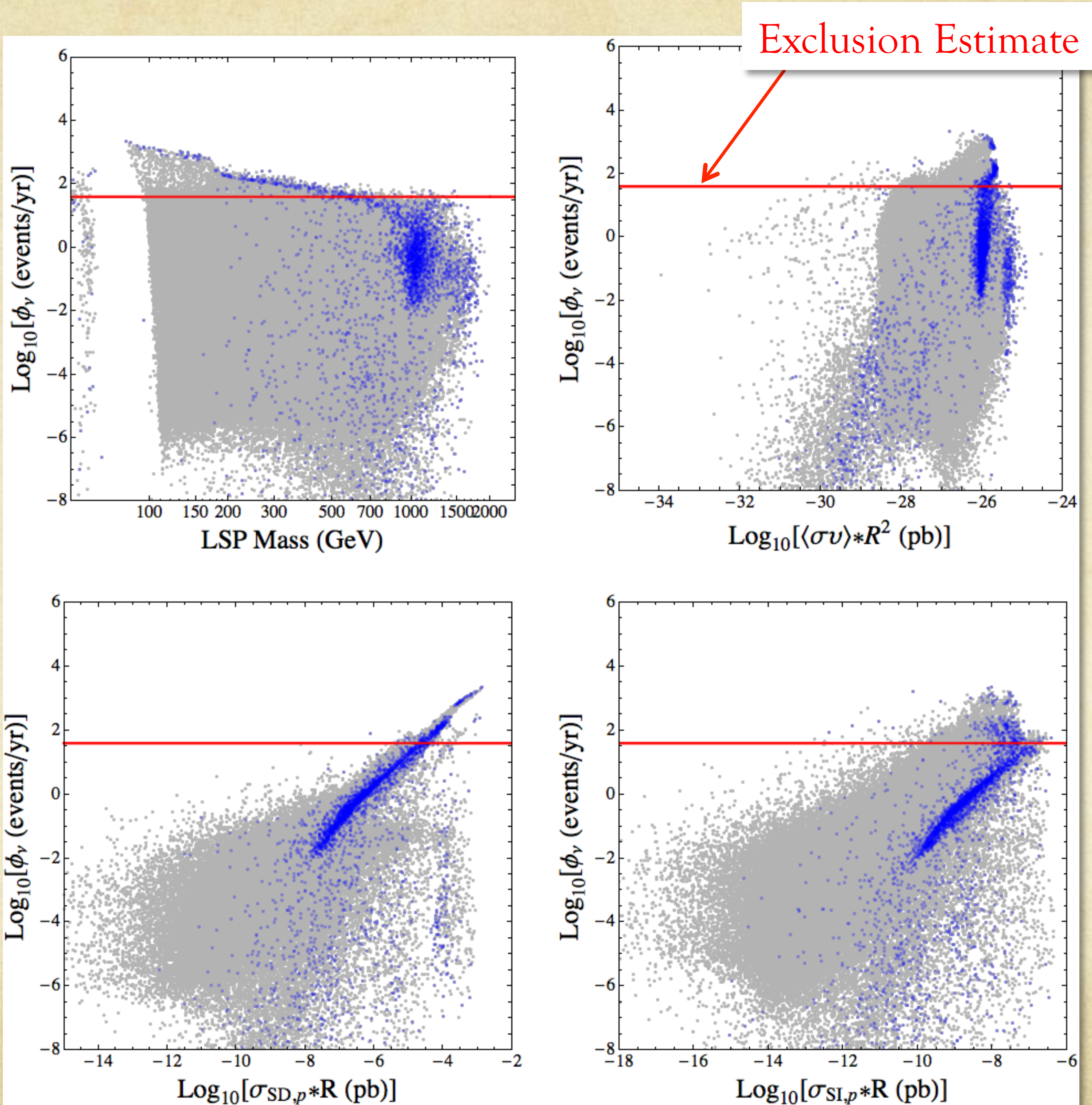
Spin-Dependent:

Currently: None of our pMSSM models are constrained by terrestrial SD-DD experiments

Far future: Will show COUPP500 3-yr forecast (R. Nielson, Aspen slides) in what follows.

IC/DC Basic Results...

Log_{10}[Detected Signal Rate /yr]



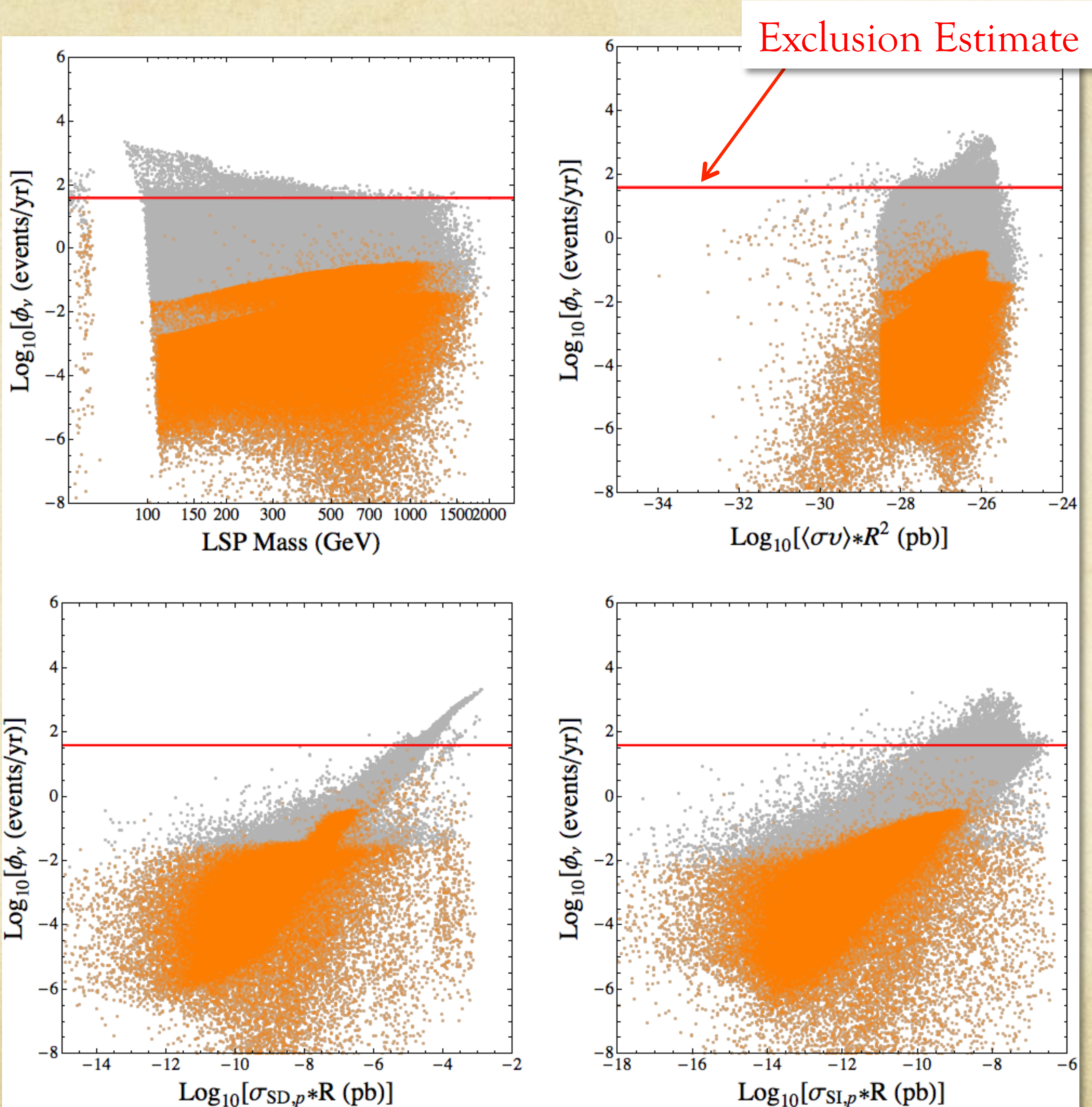
Grey Points:
All pMSSM models
(~ 223k models)

Blue Points:
$\Omega h^2|_{LSP}$ >= 0.1 Models
(3034 models)

Thermal cosmology is assumed:

$$R = \frac{\Omega h^2|_{LSP}}{\Omega h^2|_{WMAP}}$$

Log$_{10}$[Detected Signal Rate /yr]



Orange Points:

Out-of-Equilibrium ($2\Gamma_a/C_c < 0.9$) models (~ 47% of all models!)

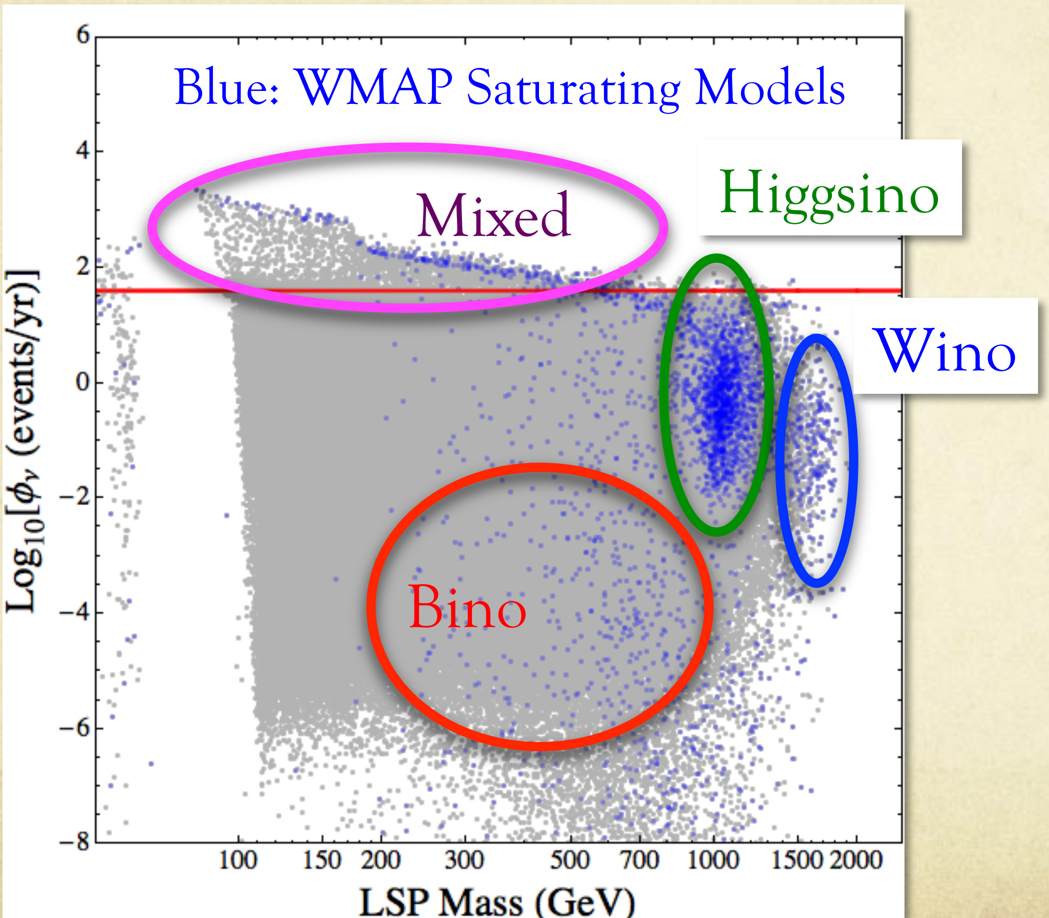
Very different than previous pMSSM model set (~7% OOE mods)

...Lower scattering cross-sections, heavier squarks, more heavy Winos...

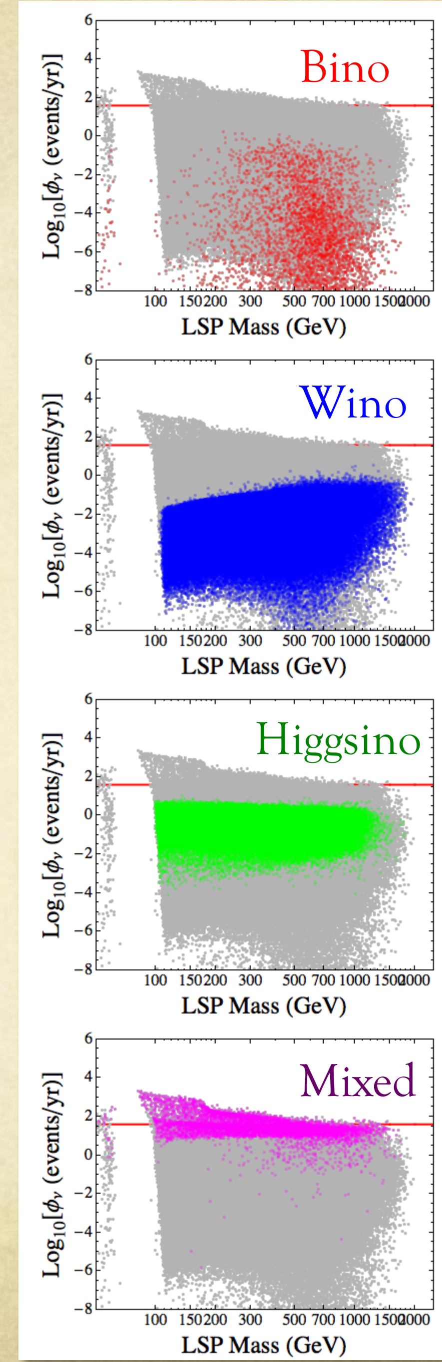
None of the Out-of-equilibrium Models can be excluded by IC/DC

Nearly all mixed neutralinos saturating WMAP with $m_{LSP}<500$GeV can be probed.

These kinds of neutralino make up most of WMAP saturating models with $m_{LSP}<500$GeV (except binos)



Arbitrary Relic Density (<WMAP)...



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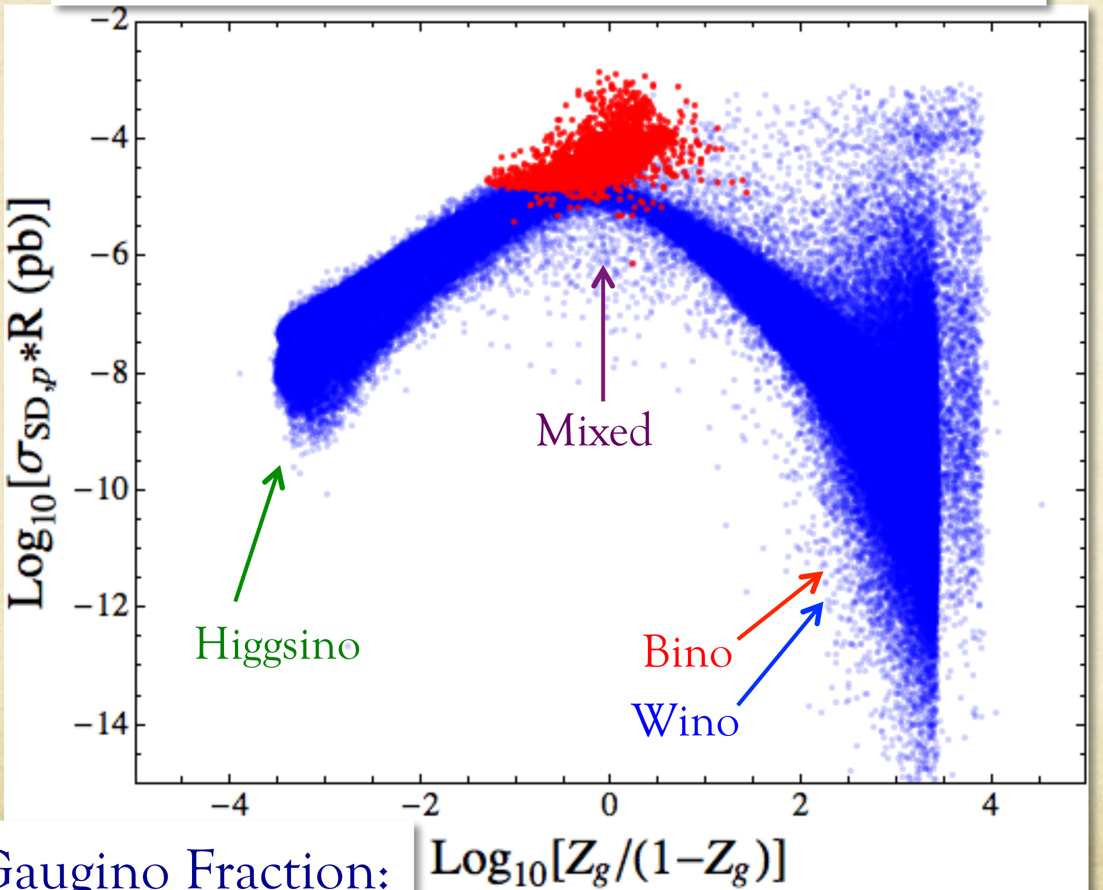
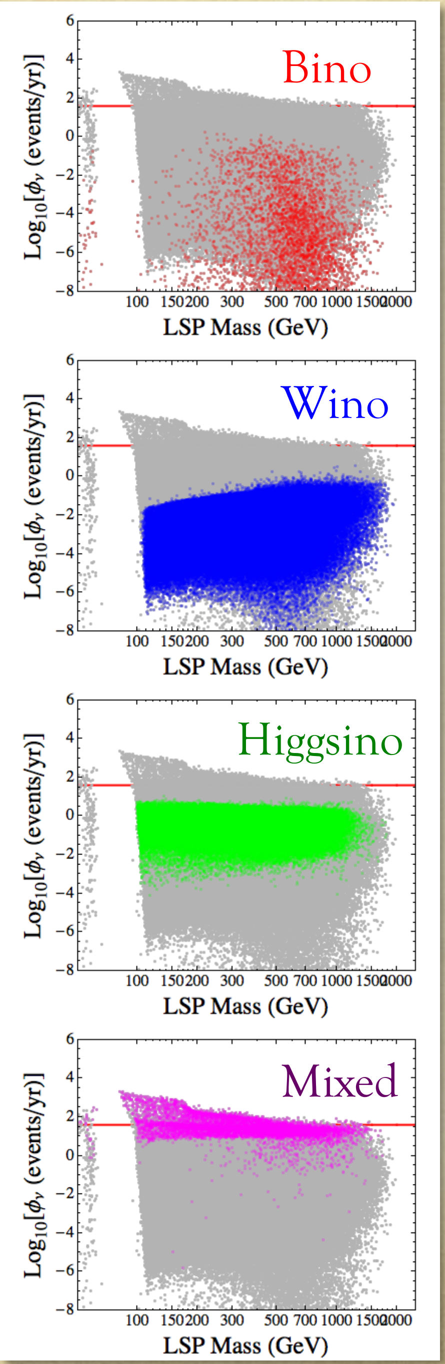
IC/DC Excluded (Red), Non-Excluded (Blue)



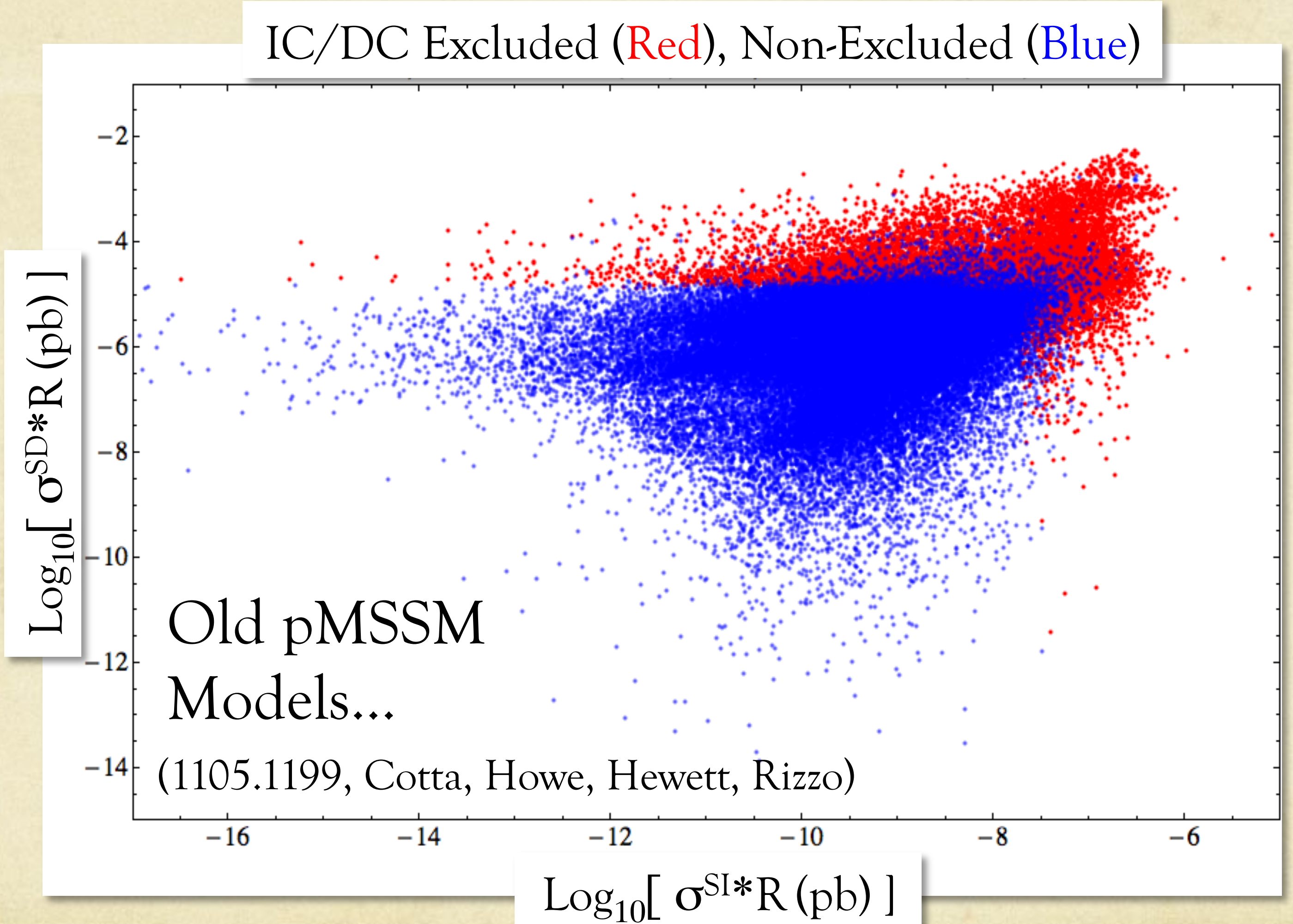
Gaugino Fraction:

Arbitrary Relic Density (<WMAP)...

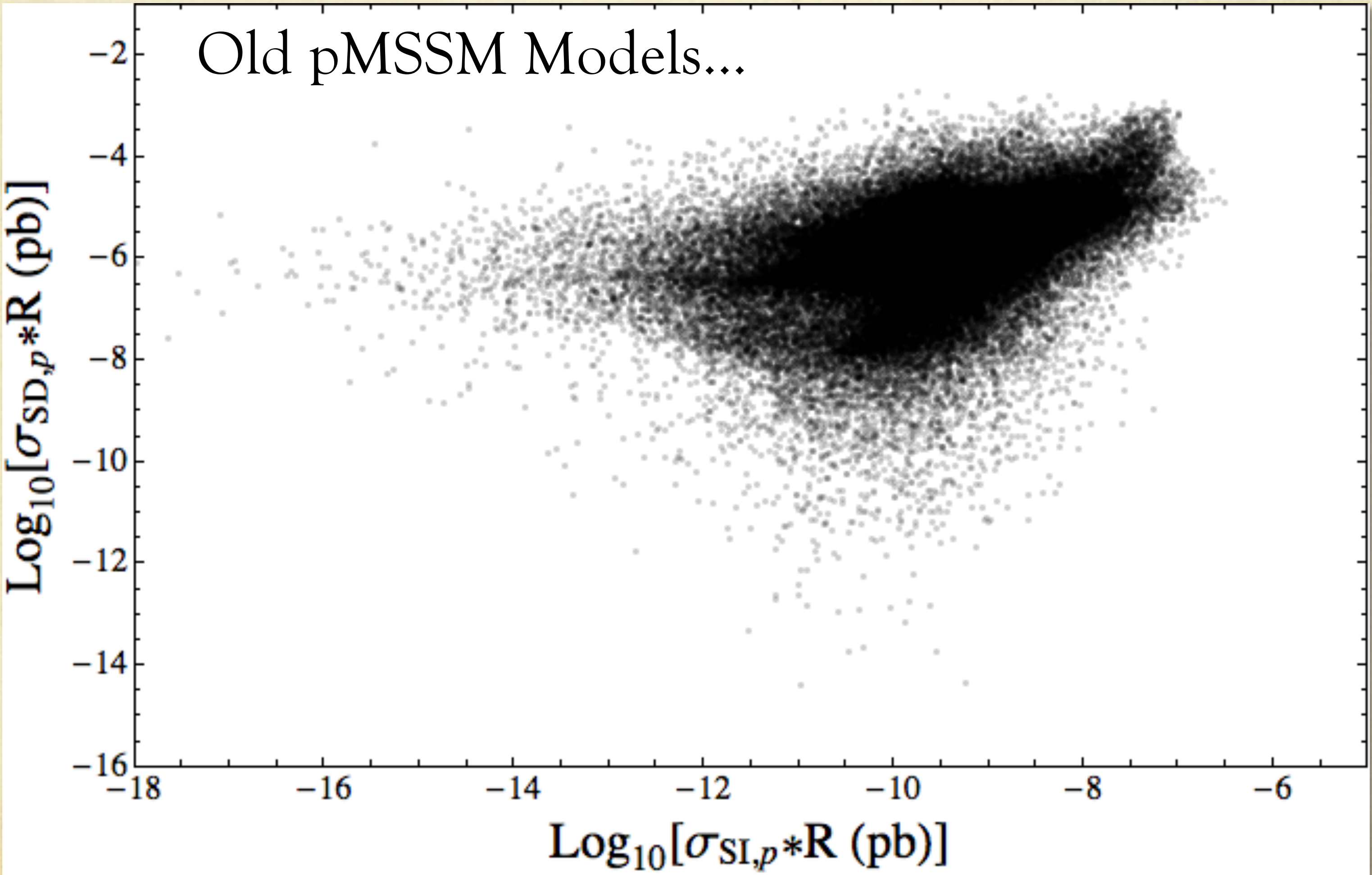


IC/DC and Direct Detection...

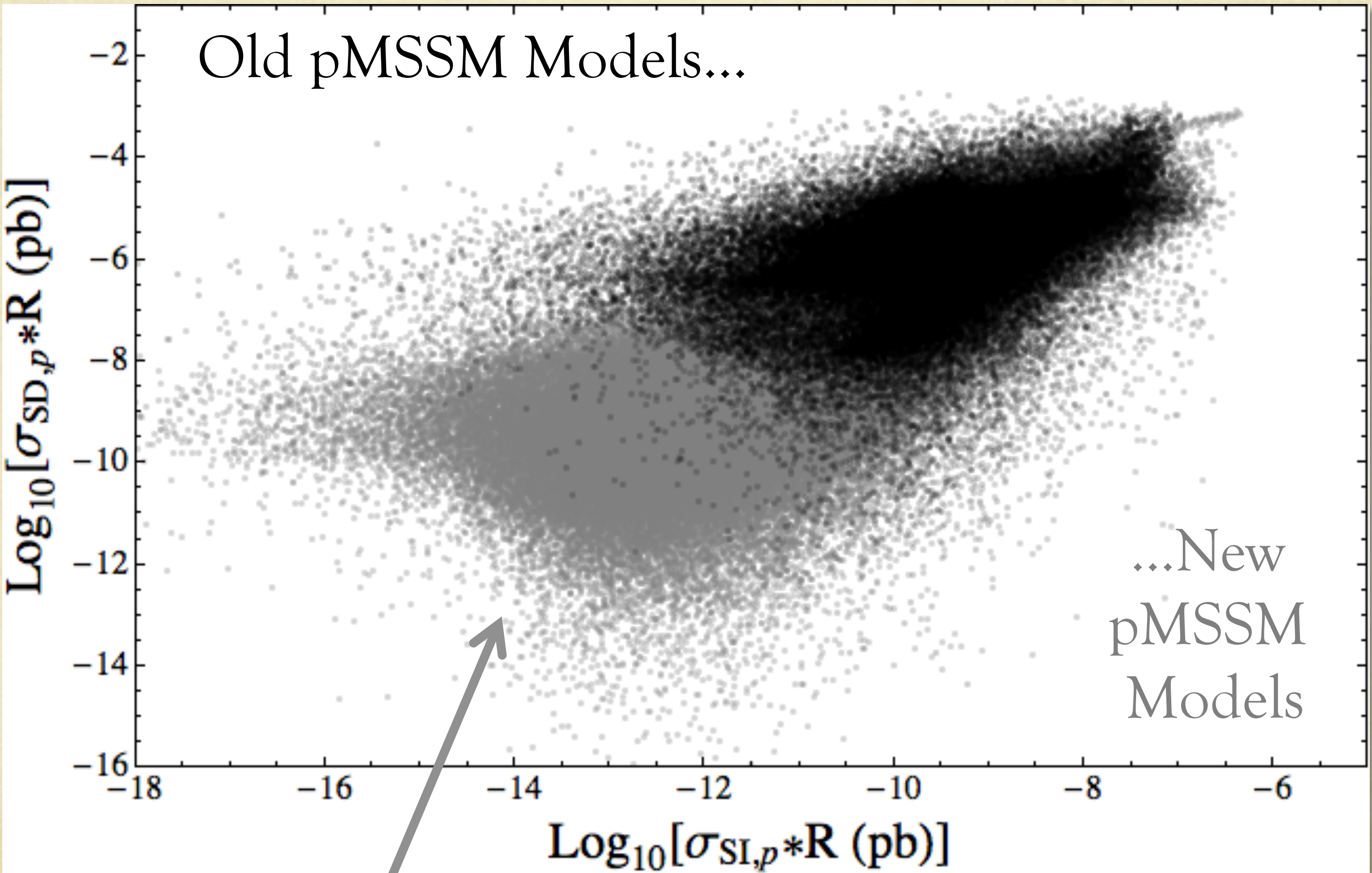
In a previous incarnation of the pMSSM...



Old pMSSM vs. New pMSSM...

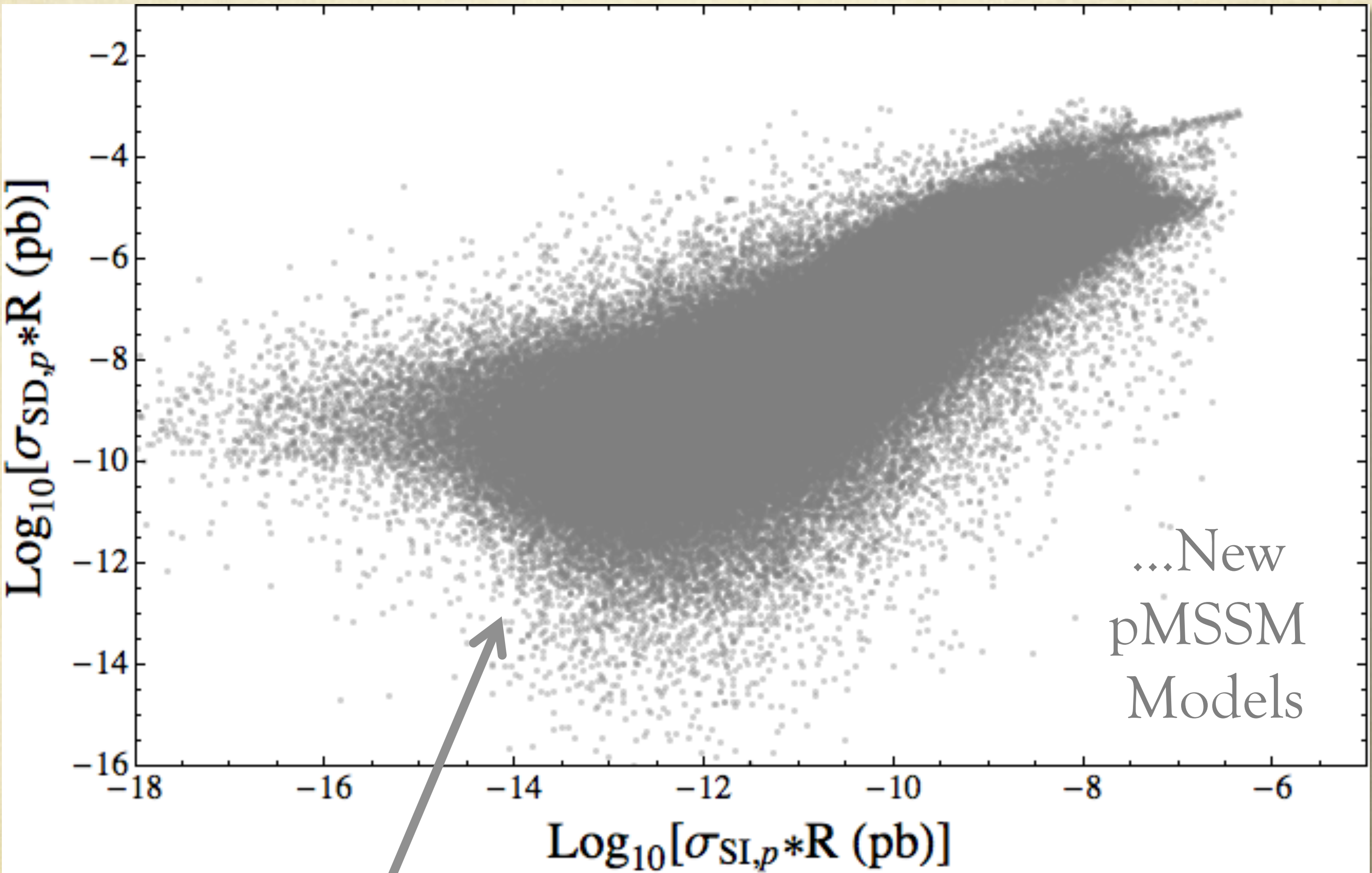


Old pMSSM vs. New pMSSM...



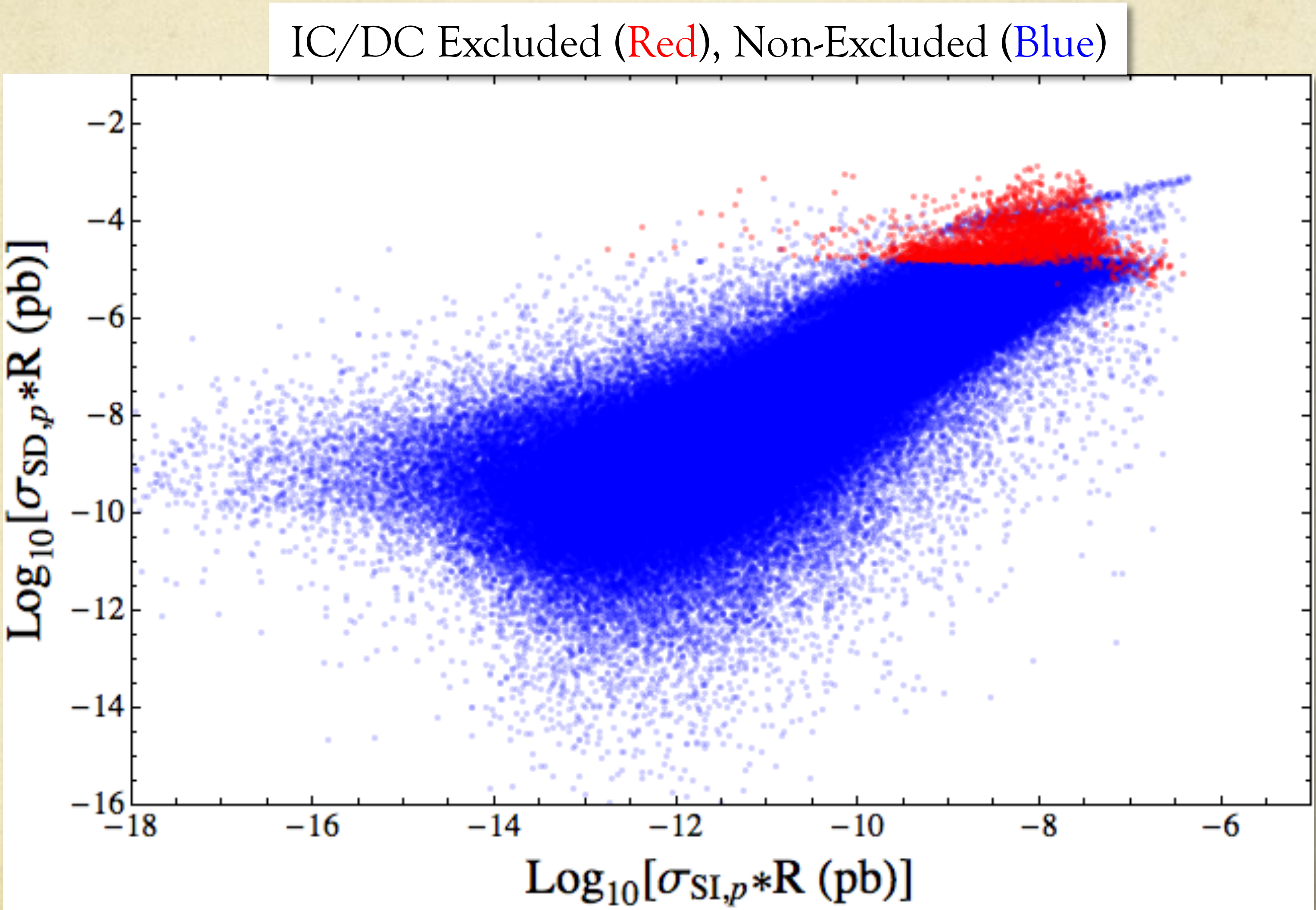
Heavier spectra + LHC: Many more models with low scattering cross-sections

Old pMSSM vs. New pMSSM...

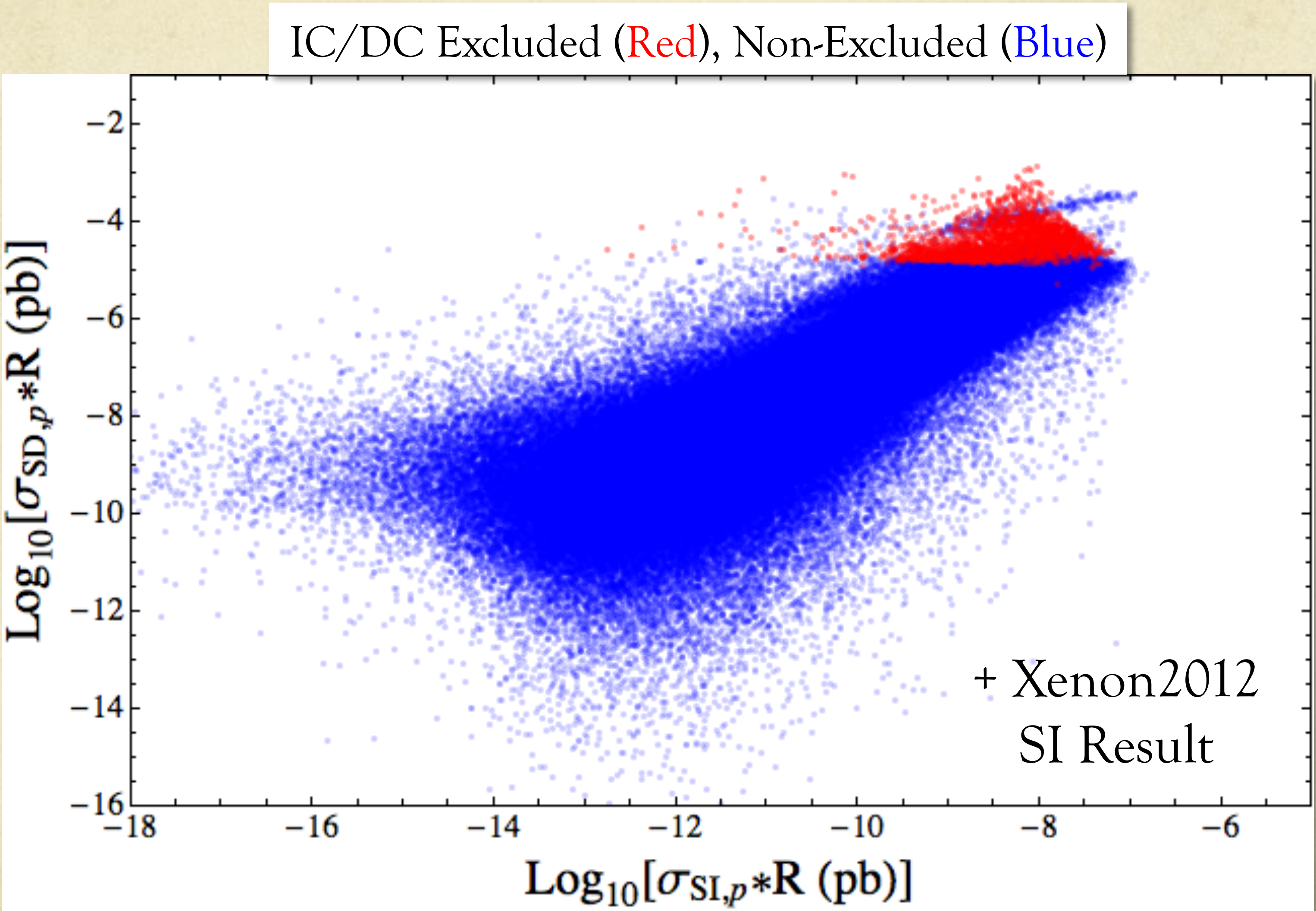


Heavier spectra + LHC: Many more models with low scattering cross-sections

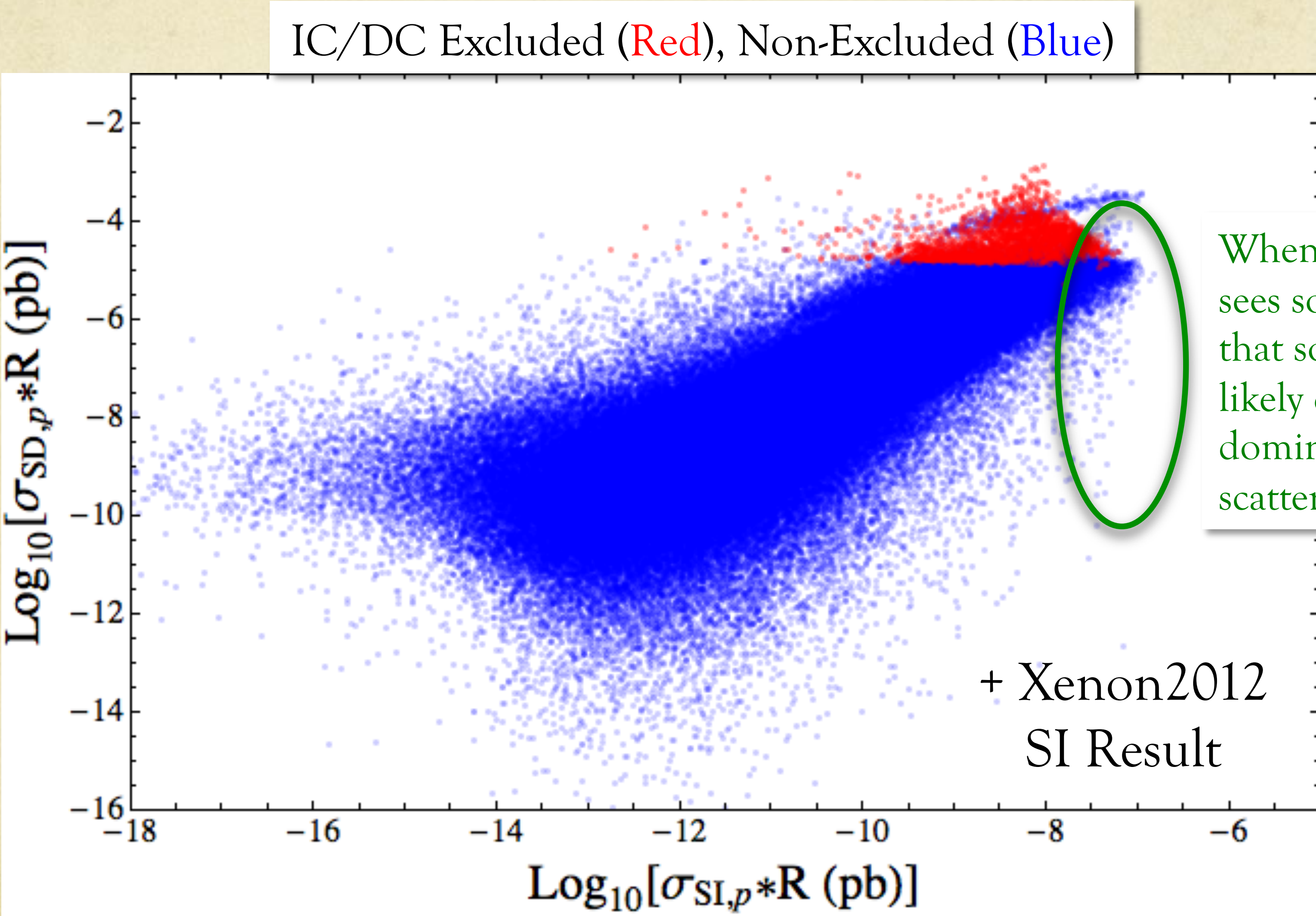
Reach in the SD vs. SI Plane...



Reach in the SD vs. SI Plane...



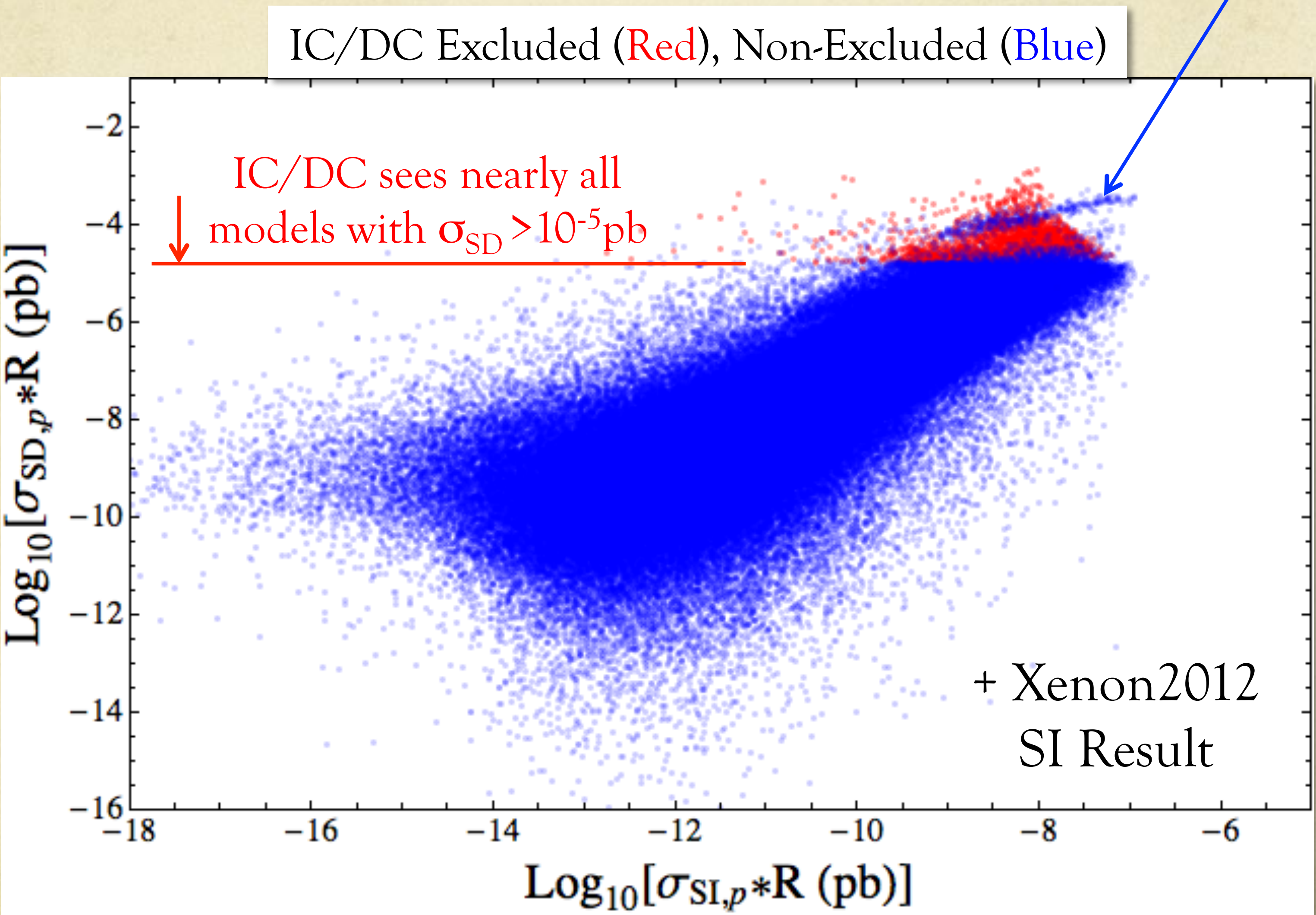
Reach in the SD vs. SI Plane...



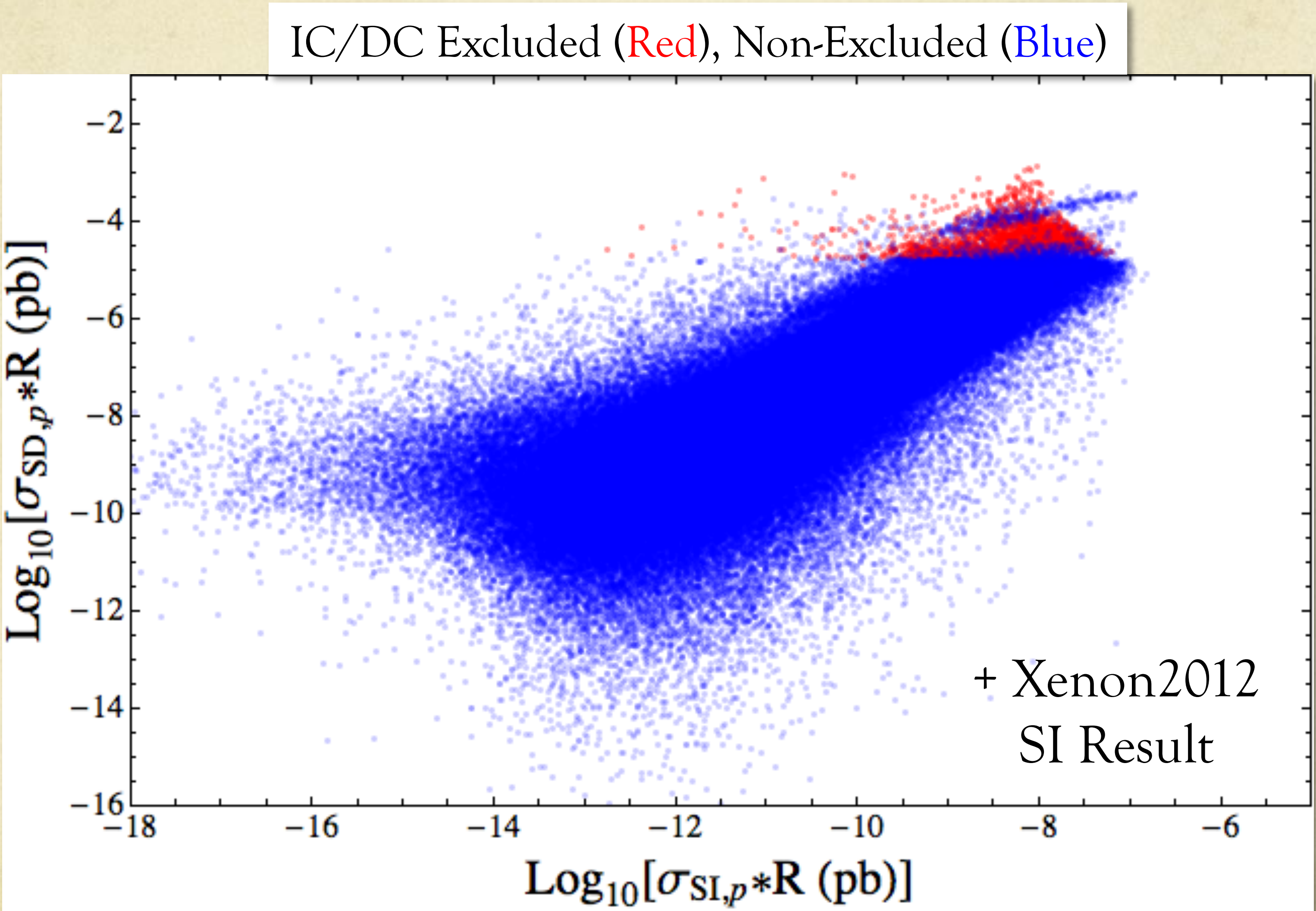
When IC/DC sees something, that something is likely captured dominantly via SD scattering...

Reach in the SD vs. SI Plane...

Except for, e.g., light-flavored squark coannihilators

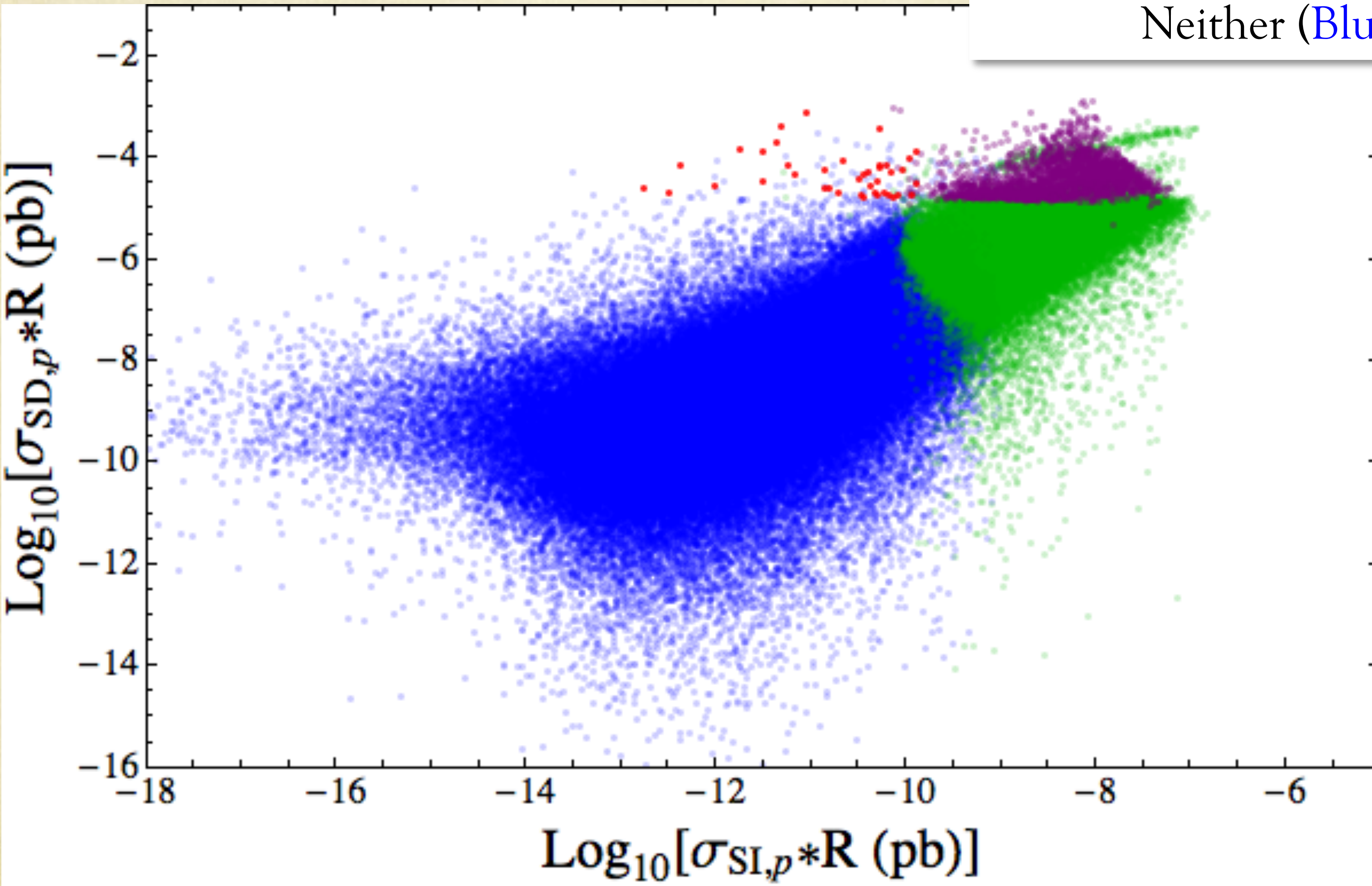


Comparing with Future Direct Detection Expts...



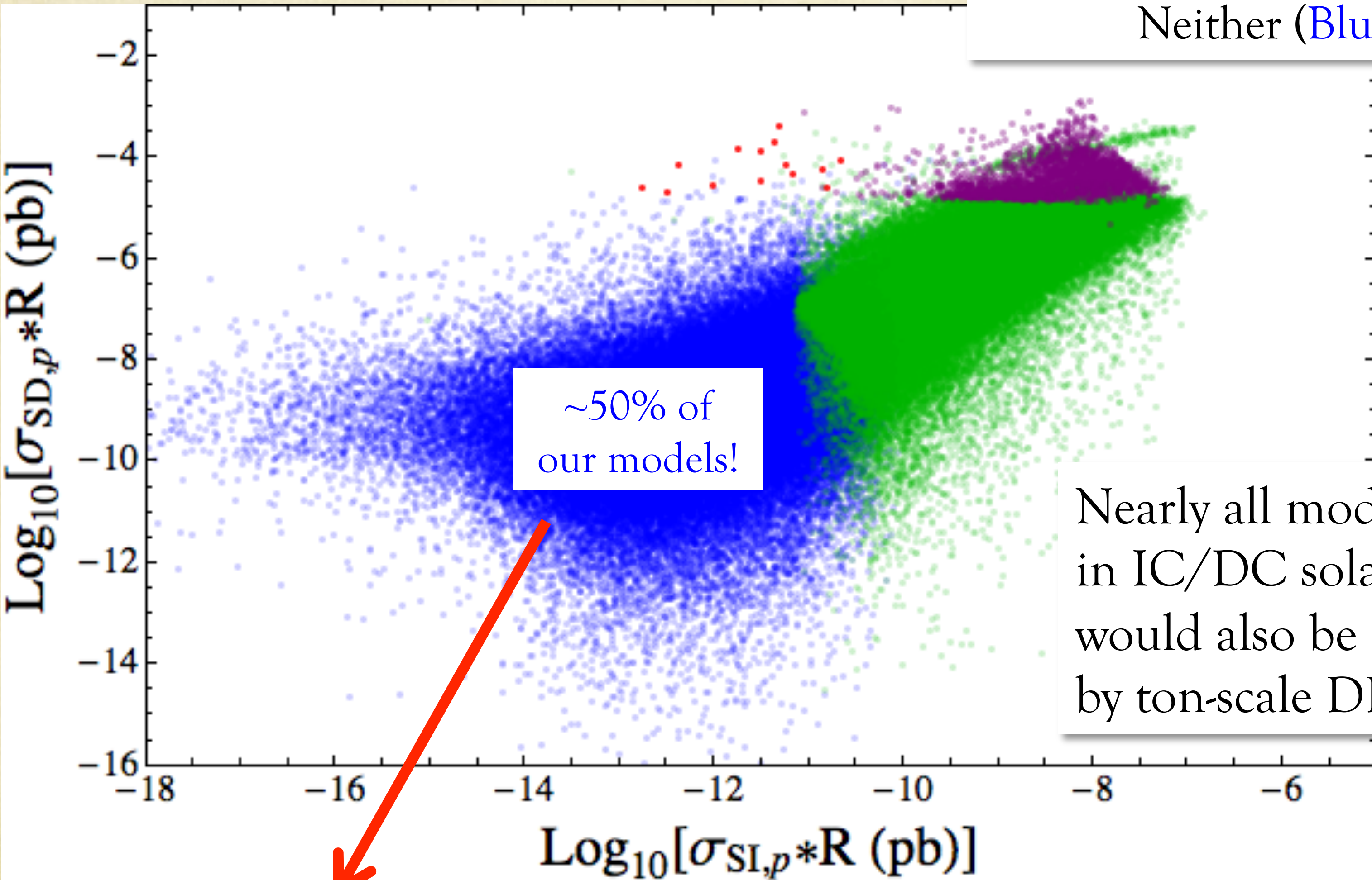
Xenon-1Ton and IC/DC...

Excluded by...
IC/DC + Xenon1T (Purple),
Xenon1T only (Green),
IC/DC only (Red),
Neither (Blue),



LUX+ZEPLIN and IC/DC...

Excluded by...
IC/DC + LZ (Purple),
LZ only (Green),
IC/DC only (Red),
Neither (Blue),



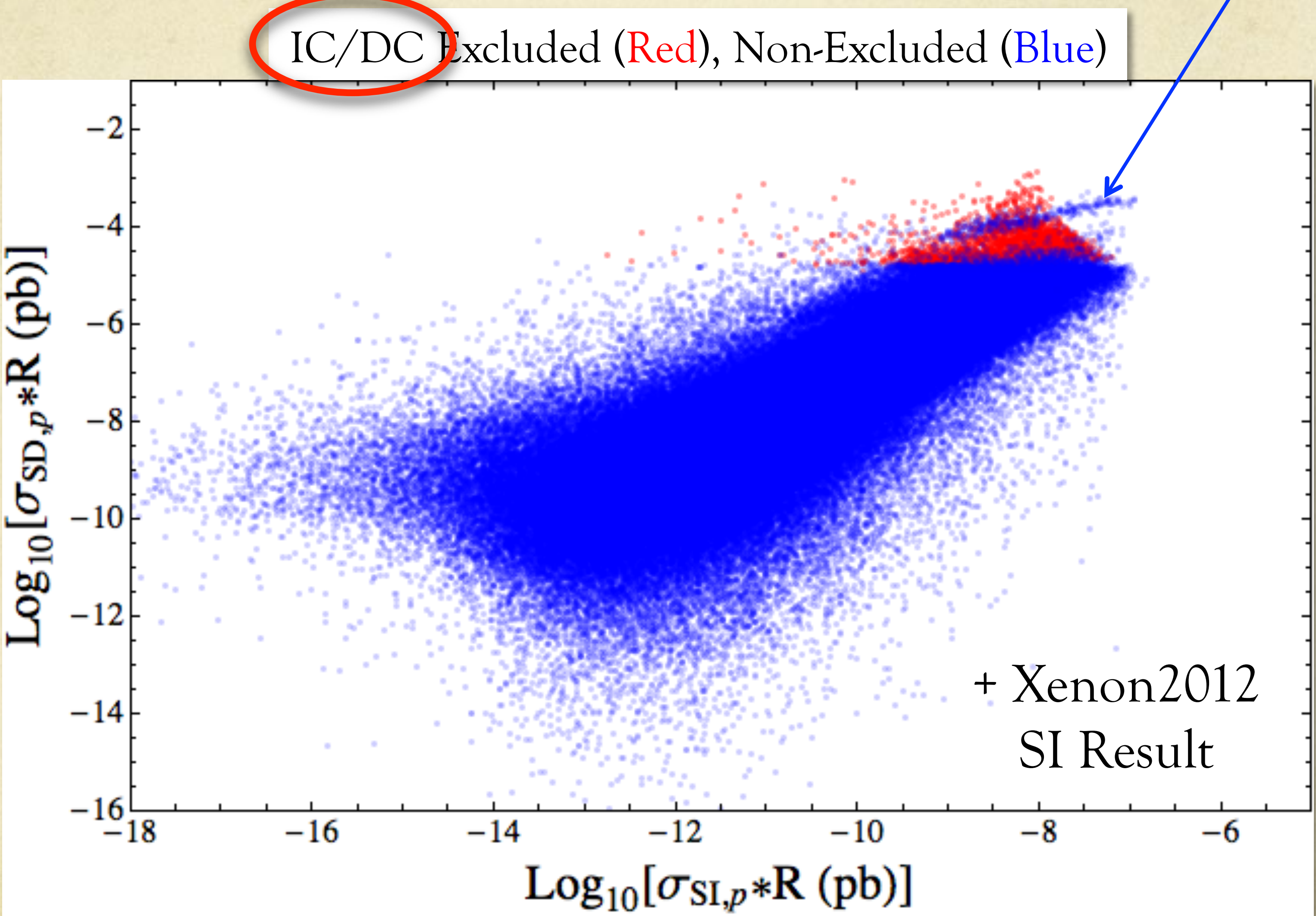
Nearly all models seen in IC/DC solar search would also be probed by ton-scale DD expts.

How will we ever see these??? See R.C., A. Drlica-Wagner, A. Ismail & T. Rizzo Talks

(Most are very hard to see in DD and even at the LHC... answer is: with CTA)

Coupp-500...

Except for, e.g., light-flavored squark coannihilators



COUPP-500...

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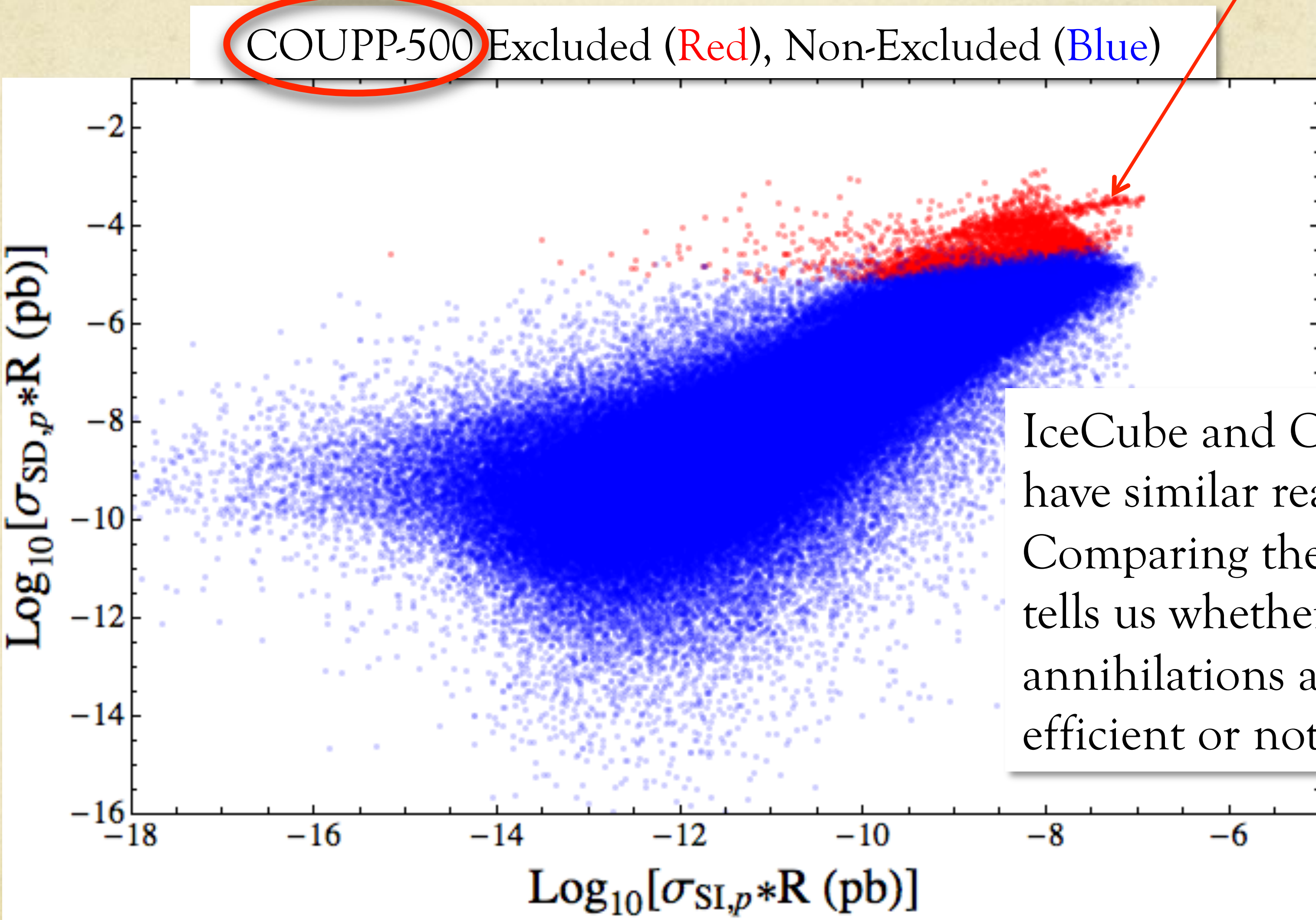
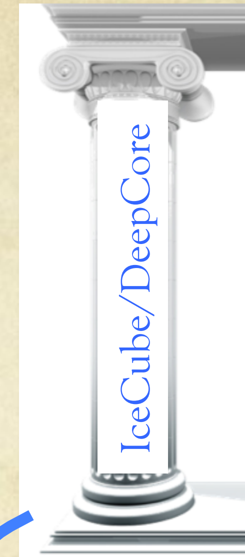


IceCube and COUPP have similar reach. Comparing the two tells us whether annihilations are still efficient or not.

Conclusions...



The IC/DC solar DM search is very unique:

It probes SUSY space in a manner similar to direct detection experiments, though with very different systematics (e.g., local DM density averaging) and provides additional information (annihilation).

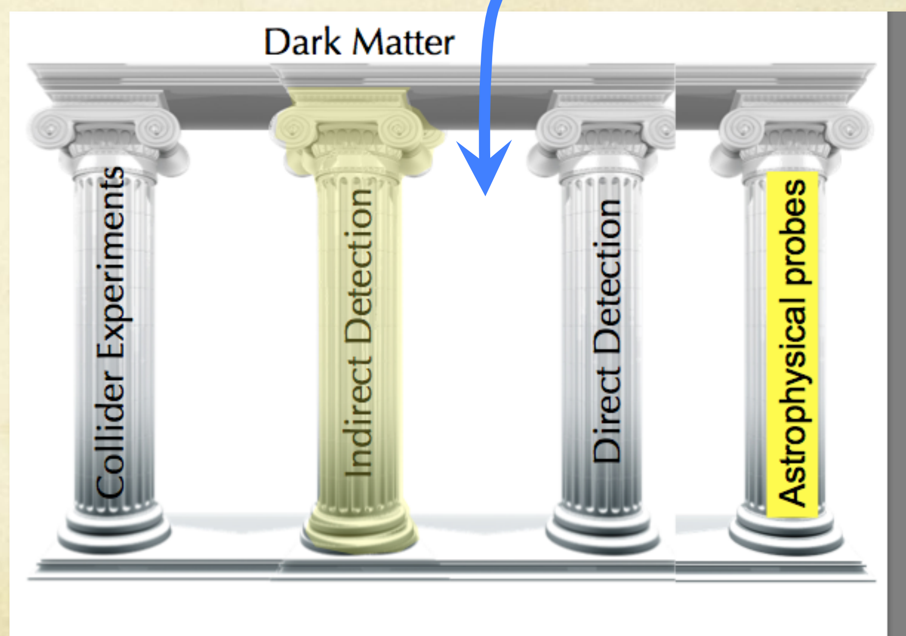
We are happy to do better:

Particularly for the IC/DC analysis although what we have already is probably qualitatively correct

If we don't have a significant probe of $\langle\sigma\upsilon\rangle$ we miss 50% of our pMSSM models entirely...

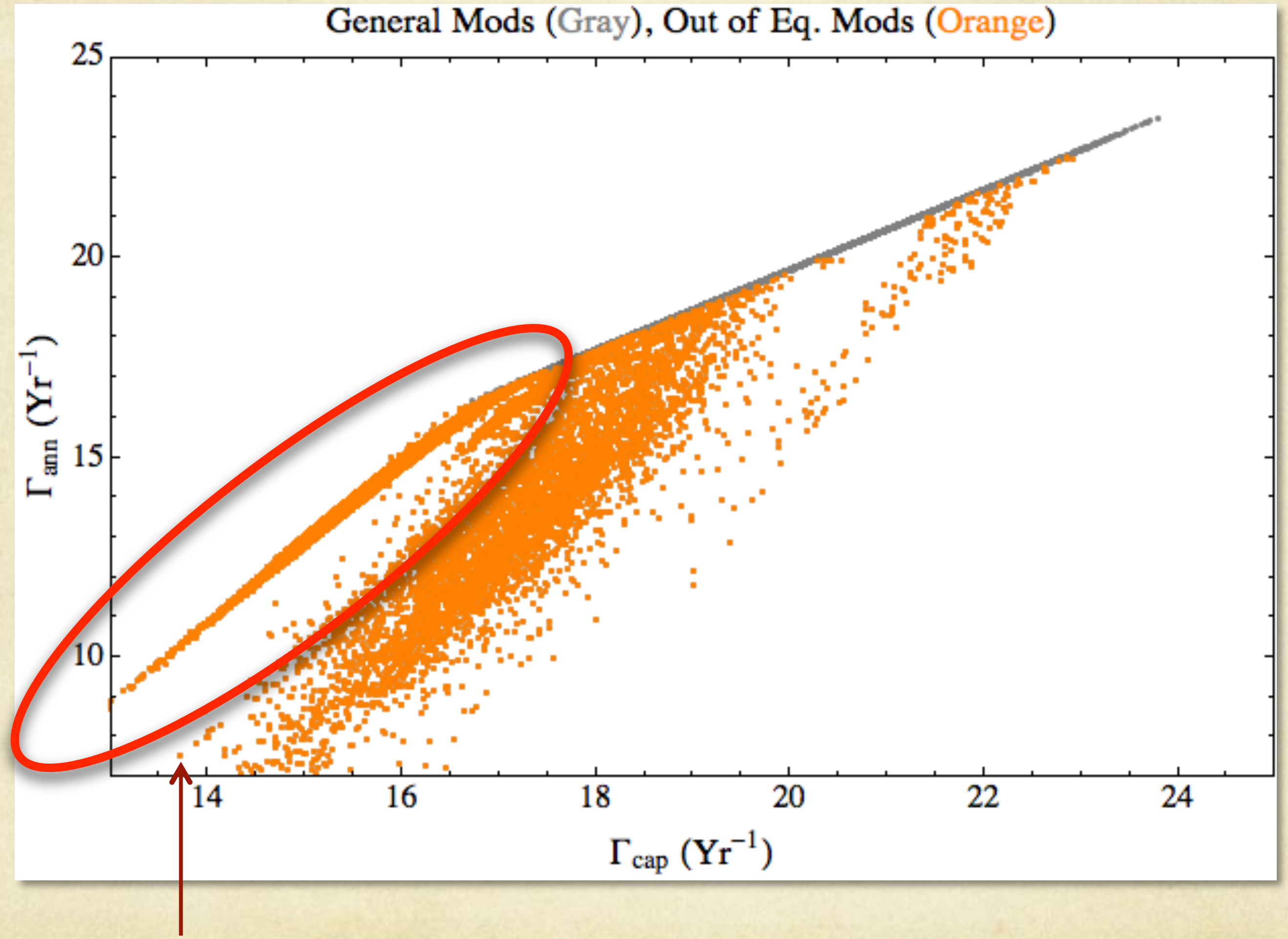
Need something like a CTA.

See: R.C., A. Drlica-Wagner, A. Ismail & T. Rizzo Talks



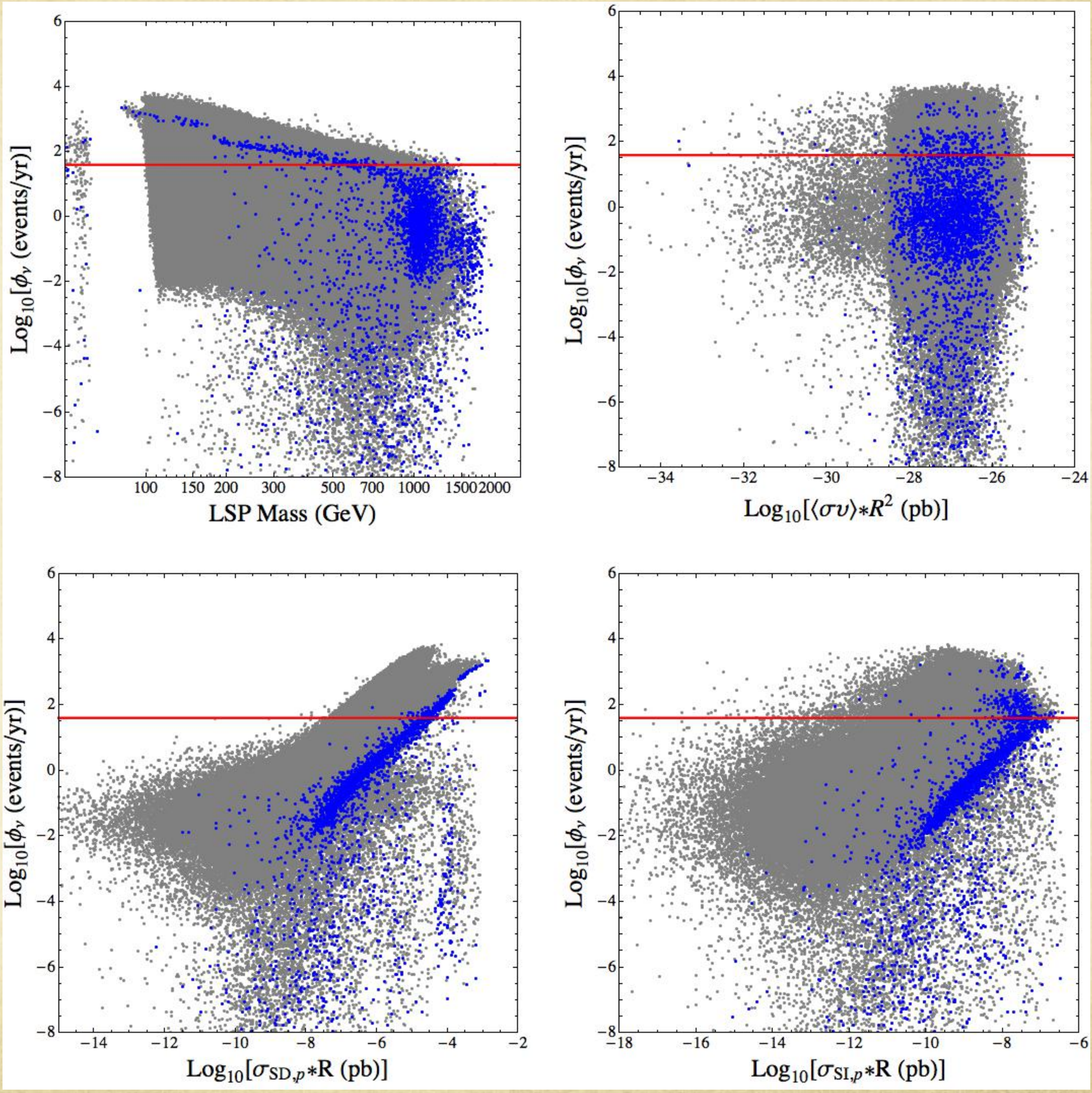
Backup Slides...

OOE in the new pMSSM model set



This is all new (and there are a ton of models in here!)

Non-Thermal Exclusions:



LSP Relic Density...

We always assume thermal WIMP freeze-out. Many of the LSPs in our set have depleted DM abundance $(\Omega h^2|_{LSP} < \Omega h^2|_{WMAP})$ so we must be careful to scale observables by the appropriate power of $R = (\Omega h^2|_{LSP} / \Omega h^2|_{WMAP})$, i.e.,

In Equilibrium:

$$\Gamma_a \sim C_c/2 = (1/2)^*(a_{SI}\sigma^{SI} + a_{SD}\sigma^{SD})^*\rho_{\chi,halo}$$

with $\rho_{\chi,halo} = R^*\rho_0$ and $\rho_0 \sim 0.3\ \mathrm{GeV/cm^3}$

Although IceCube observes annihilating WIMPs, the signals scale as $\sigma_{elastic}{}^*R$ like terrestrial direct detection experiments (CDMS, COUPP, etc.)...

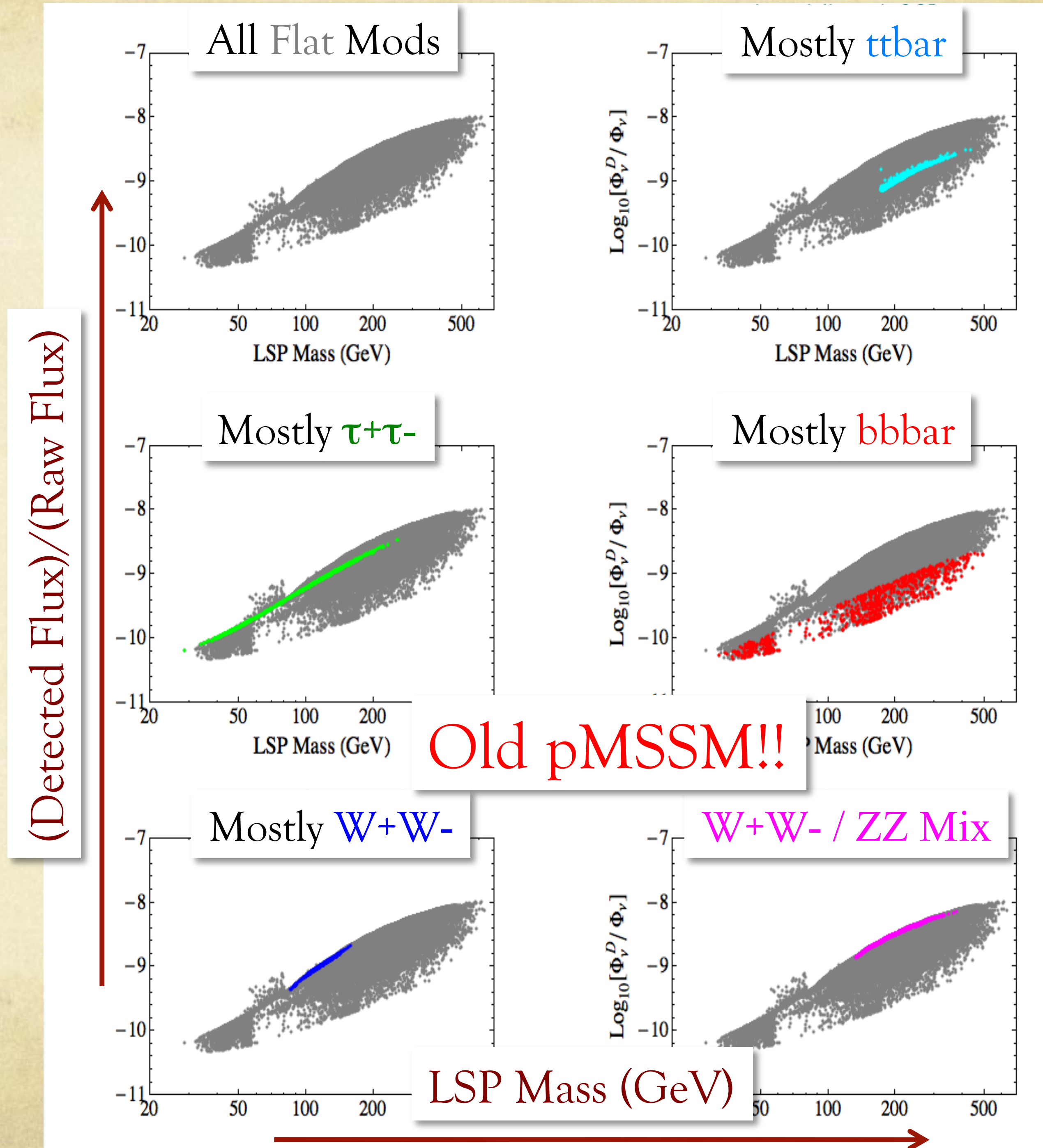
...and NOT as $<\sigma v>^*R^2$ like other searches for DM annihilation (FERMI, HESS, PAMELA, IceCube GC observation, etc.).

The *Shape* of the Signal ν Spectra...

The IC/DC effective area is sharply dependent on the rigidity of the spectra.

Spectral *Shape* is determined by the annihilation rates into various Standard Model final states.

Different final states can see very different effective areas.



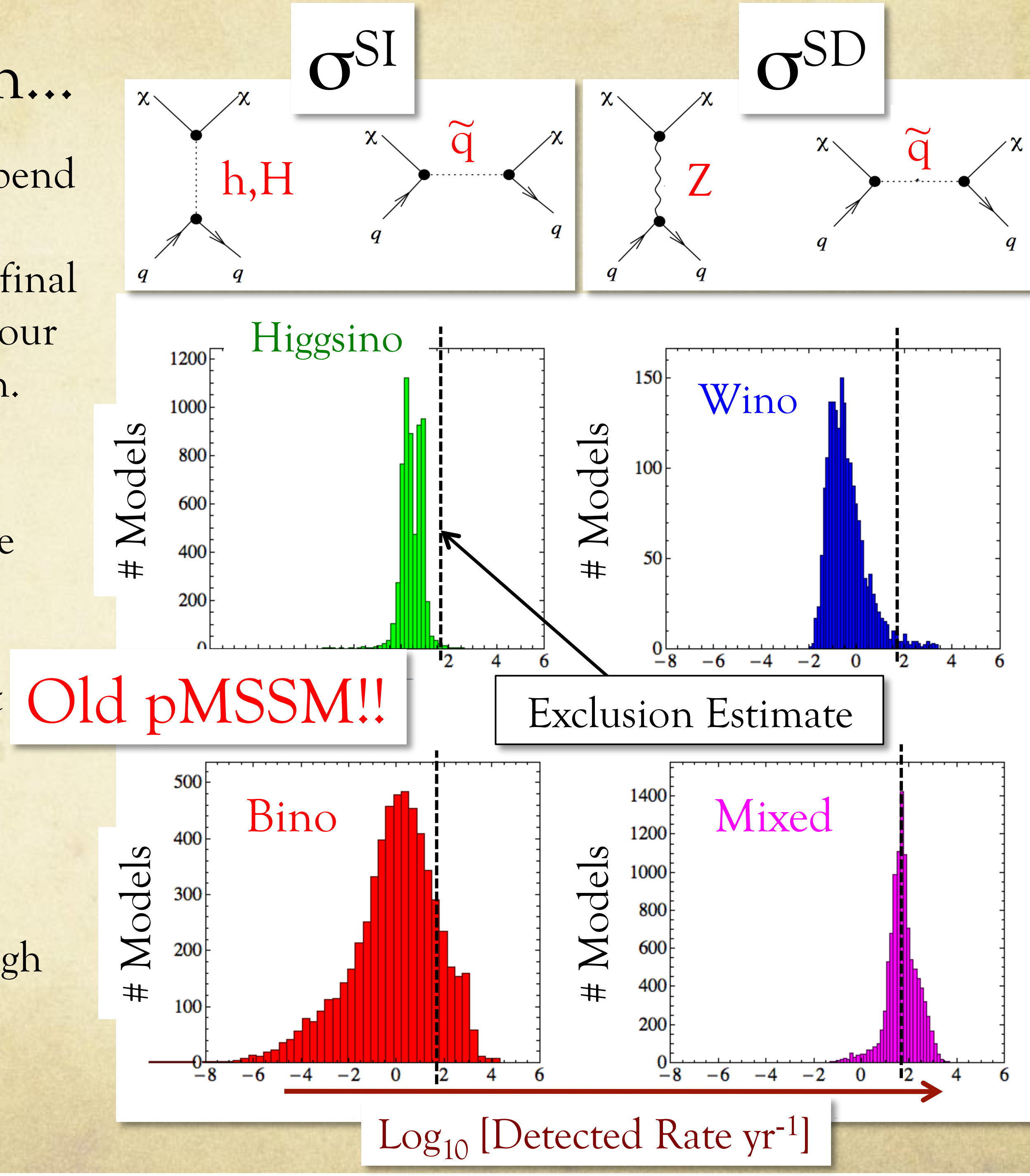
LSP Composition...

Since *overall* signal rates depend on σ^{SI}, σ^{SD}, R and the annihilation rates into SM final states it is useful to classify our models by LSP composition. We see:

• Pure Winos/Higgsinos are hard to see (relic density)

•Bino predictions vary a lot they depend on (scanned) sfermion masses

• Mixed LSPs (often B-H) typically have large rates (high relic density + hard f.s. channels).



LHC Searches (ATLAS 7TeV $1fb^{-1}$ 4jet-0lepton):

"PASS"= $S/\sqrt{B}>5$ (ATLAS), or $\Phi^D_\nu<100$ events/yr (IC/DC)

"FAIL"= $S/\sqrt{B}<5$ (ATLAS), or $\Phi^D_\nu<100$ events/yr (IC/DC)